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CASE STUDIES OF USES OF THE PIPE EXPLORER™ SYSTEM

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ABSTRACT

The Pipe Explorer™ system is an effective and inherently clean method for conducting radiological and video surveys in pipes and ducts. The system has been used for these purposes in support of facility decontamination and decommissioning activities at both commercial and government facilities. The sites where the system has been used include six DOE sites and two commercial nuclear reactors. An overview of the methods and results for each of these applications is presented along with a discussion of the cost savings realized from uses of the Pipe Explorer™ system. Furthermore, an analysis of issues associated with surveys for free-release of piping that arouse through the field uses of the system is presented.

I. INTRODUCTION

The United States nuclear industry is increasingly involved with the decommissioning and decontamination (D&D) of its nuclear power plants and nuclear process facilities. This includes both government and commercially owned sites. A difficult and expensive issue with the D&D of these facilities is the miles of piping associated with the buildings. When pipes are not contaminated it is difficult to certify this since the measurement geometry associated with pipe internals is problematic. Conversely, in many situations pipes are known to be contaminated but are embedded in concrete or are located beneath concrete slabs. This makes the costs associated with removing the pipes and disposing of them as radioactive waste extremely high. Cost estimates for removing drain lines beneath a concrete slab are as high as $1,200 per linear foot[1]. Therefore, a cost-effective alternative is to clean the pipe interiors and survey them for free release.

In either situation there is a need to be able to obtain accurate measurements of the internal surface activity levels of radioactive contamination in pipes. Many systems for conducting these measurements, such as robotic pipe crawlers or detectors directly inserted into the pipes, are limited in their effectiveness. For instance, most facilities will have multiple piping systems that must be surveyed. Therefore, in order to avoid cross contamination of piping systems, the survey instrument and its associated cabling must be assured of being clean before it can be reused in another pipe. Furthermore, there is no way to prevent spreading contamination within a given pipe if removable contamination is present, since the design of these devices places them in direct contact with the pipe wall. Robotic devices and direct insertion techniques are also limited in the number of elbows they can negotiate within a piping system. Typical results with both types of methods are limited to 0 - 3 elbows. Similarly these methods do not work well in piping systems that have vertical sections or pipes that have significant obstructions or debris.

To overcome these limitations, Science & Engineering Associates, Inc. (SEA) has developed a unique and effective technology called the Pipe Explorer™ for measuring radioactive contamination levels inside of pipes. The system, developed with the support of the Department of Energy (DOE) Office of Science and Technology through a contract administered by the Federal Energy Technology Center (FETC), solves the D&D problem of conducting radiological and video surveys of pipe internals.

The Pipe Explorer™ technology uses a pneumatically emplaced tubular membrane to transport characterization tools into pipes, drain lines, and ducts. The tools available for use with the system include alpha, beta, and gamma radiation detectors; video cameras; and pipe locator beacons. The system uses an airtight membrane configured so that when it is pressurized it inverts into a pipe. As it inverts, the pressure force on the end of the membrane is adequate to tow a detector around multiple elbows and through several hundred feet of piping. This technology not only provides an effective transportation method for detectors, but it also provides a clean conduit through which detectors can travel.

A. Description of the System

The primary components of the Pipe Explorer™ technology are illustrated in Figure 1. The core of the system is an airtight membrane that is initially spooled inside of a canister. The end of the membrane protruding out of the canister is folded over and sealed around the outlet of the canister (Stage 1 of Figure 1). When the canister is pressurized in this configuration, the air pressure on the membrane causes it to be pulled from the spool (Stage 2 of Figure 1). Thus, as membrane is fed from the deployment canister it travels inside of the membrane that has been deployed ahead of it until it reaches the inversion point. The inversion point continually advances in the pipe as the membrane rolls up against the pipe wall. This continues until the membrane is completely off the spool. At this point in the deployment sequence, half of the membrane is deployed against the pipe wall, while the other half is still inside of the deployed membrane (Stage 3 of Figure 1). A characterization tool such as a radiation detector is attached to the end of the membrane and is towed into the pipe as the membrane continues to invert. The detector cabling is also fed from the spool and towed into the pipe (Stage 4 of Figure 1).

To retrieve the system, the cabling and detector, are wound back onto the spool, which pulls the membrane back inside of itself. Since the membrane is inverting, it is retrieved inside out. Therefore, workers handle only the clean side of the membrane (this is analogous to the way latex gloves are removed when doffing PPE). After each survey the membrane is disposed of as waste, generating about 0.01 m^3 of compacted waste for a 100-m pipe survey.

The Pipe Explorer™ system can thus be used to move a detector freely back and forth through a pipe, while the detector output and position are recorded. As a result, the Pipe Explorer™ system provides comprehensive video surveys and detailed characterization of the location and abundance of radioactive contamination in pipes.

The Pipe Explorer™ sensor deployment method of using an inverting membrane provides a clean conduit through which the detector travels. This protects both the detector and the workers handling it. No worker or equipment contamination has occurred during thousands of feet of Pipe Explorer™ surveys conducted in contaminated piping. Furthermore, measurements are inherently more reliable with the Pipe Explorer. A detector transported in any other fashion runs the risk of removable contamination adhering to the sensor, which can cause erroneously high or false positive readings.

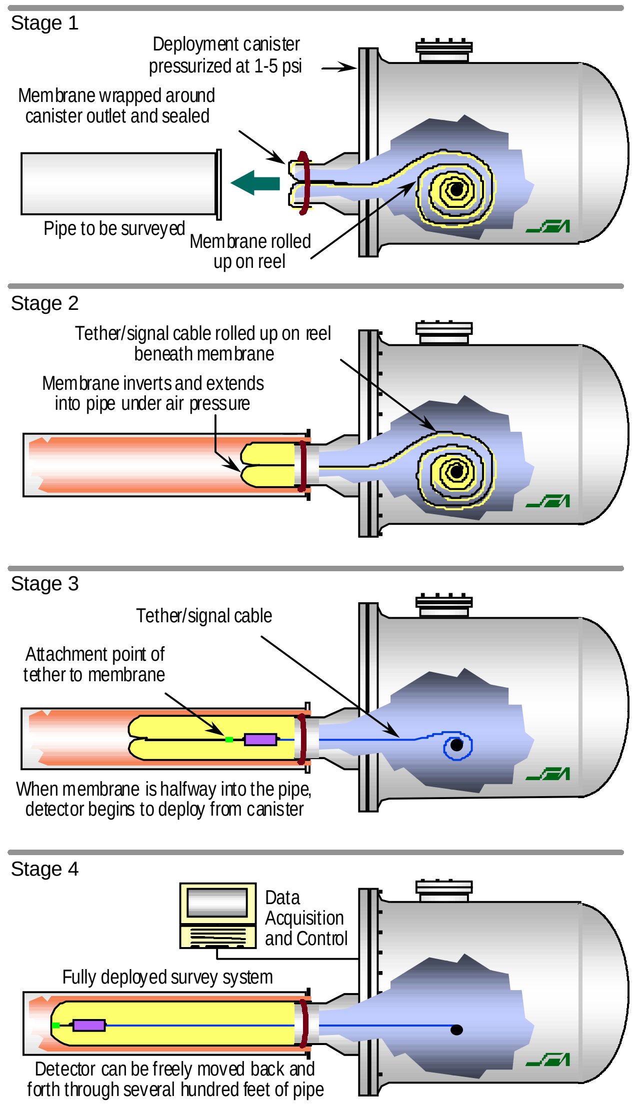

Figure 1. Sketch showing the Pipe Explorer™ system deployment sequence.

B. Alpha Detection

The deployment methodology of the Pipe Explorer™ presents some unique measurement issues. For example, the membrane used with the system provides some attenuation of the radiation. For gamma and higher energy beta radiation (>400 keV) the effect is negligible. However, with alpha particles the effect cannot be ignored. To accomplish alpha measurements with the Pipe Explorer™ system, a special scintillating membrane was developed. This configuration of the inverting membrane deployment technology, called Alpha Explorer™, uses a membrane material impregnated with an alpha sensitive scintillator (zinc sulfide) to turn the membrane into an integral part of the detection system. The light pulses emanating from the membrane due to alpha particle interactions are recorded by a photo multiplier tube towed through the pipe in the same fashion that beta/gamma detectors are towed. Figure 2 shows the basic methodology of the Alpha Explorer™ system.

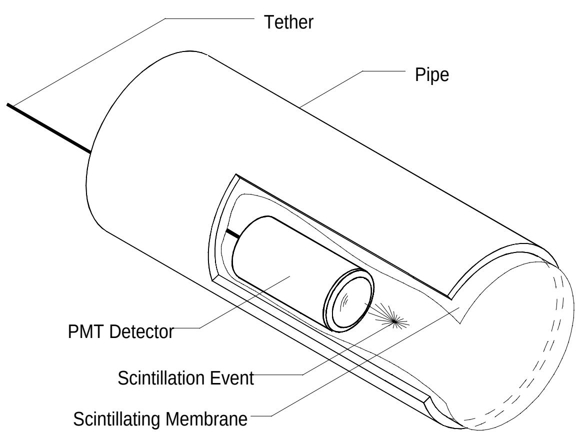

Figure 2. Basic configuration of the alpha measurement process employed with the Pipe Explorer™.

II. PIPE EXPLORER™ USES

The Pipe Explorer™ system has been used for alpha, beta, gamma, and video surveys of over 6,000 feet of piping. Two fully automated and two manually operated Pipe Explorer™ deployment systems have been used to conduct these surveys (Figure 3 shows one of the automated systems in use). The surveys have included pipes with up to 8 elbows and with vertical runs in excess of 9 m. Detectors have been successfully deployed past rocks, oil, and other debris that have obstructed up to 50 percent of the pipe's cross sectional area. The Pipe Explorer™ deployment systems are capable of conducting surveys in pipes with diameters ranging from 0.05 m (2-inches) to 1.22 m (48-inches) and survey lengths that vary from 30 m up to 300 m. The following is a chronological listing of those uses of the system. A summary of the type of surveys completed and the outcome that resulted from the use of the Pipe Explorer™ data are discussed.

Figure 3. One of the automated Pipe Explorer™ systems being used to conduct radiological surveys through a floor drain at a DOE site.

A. Idaho National Environmental Engineering Laboratory
Idaho – July 1994

A feasibility demonstration of the Pipe Explorer™ system was conducted at the INEEL Chemical Processing Plant. A gamma detector was used to survey scrap piping ranging from 0.05 m (2-inches) to 0.10 m (4-inches) in diameter. In addition a mock drain line system consisting of 3-inch steel piping was surveyed to detect Cs-137 sources placed in the piping. This use of the system served as a feasibility demonstration only.

B. DOE Formerly Utilized Sites Remedial Action Program General Motors Site
Michigan – April 1995

Beta/gamma surveys were conducted in an oil drainage system to determine the location and extent of U-238 contamination. The drainage system consisted of a network of 0.1 m (4-inch) diameter pipes running underneath the concrete slab of an operational automobile parts factory. The survey data obtained with the Pipe Explorer™ system was used to determine if piping needed to be cleaned. The Pipe Explorer™ was also used after cleaning activities to verify the effectiveness of the process. The Pipe Explorer™ data allowed the site remediation contractor to grout the pipes and leave them in place instead of excavating and disposing of the pipe as radioactive waste. Subsequently, over $2 million in remediation costs were avoided. The performance of the

Pipe Explorer™ system was published in a DOE Technology Summary Report[1].

A noteworthy aspect of the use of the Pipe Explorer™ system at this site was that the quality of the data was highly dependent on the inherently clean operating method of the system. The drain lines being surveyed were heavily coated with a thick oily sludge that contained the U-238 contamination. Since the Pipe Explorer™ membranes are inverted upon retrieval, the contamination is always kept inside the polyethylene membrane material (Figure 4 shows one of the membranes after it had been retrieved from a drain line at the site). Therefore, the Pipe Explorer™ membrane protected the detectors used at this site from coming into contact with the oil. This ensured that true surface activity measurements as a function of distance were obtained, which was critical for performing the site hazard assessment[2]. Furthermore, none of the equipment became contaminated, which allowed for the system to be moved from one drain line to the next without fear of spreading the U-238 contamination. If a detector had been inserted into the pipe with either a robotic device or a direct push method then this would not have been true.

Figure 4. Photograph of a Pipe Explorer™ membrane retrieved after surveying a pipe containing oil and U-238 contamination. Note how the contamination is contained within the membrane.

C. Inhalation Toxicology Research Institute
New Mexico – November 1995

The Pipe Explorer™ system was used to conduct both gamma and beta/gamma surveys in 0.10-m (4-inch) and 0.15-m (6-inch) diameter pipelines buried beneath the concrete slab of an operational laboratory. The contaminants of concern were Cs-137 and Sr-90. In addition, video surveys were conducted to determine the integrity of the decades old piping system. The Pipe Explorer™ data showed that the majority of the piping was clean enough to avoid extensive remediation costs. Furthermore, the video data showed that the pipes were in good enough physical condition so that they could continue to be used as part of the site sewer system.

D. DOE-Grand Junction Projects Office
Colorado – February 1996

Buried drain lines were surveyed using the Pipe Explorer™ beta/gamma detector to determine U-238 contamination levels. In addition, video surveys were conducted to determine the physical condition of the piping. The pipes surveyed ranged from 0.076 m (3-inches) to 0.20 m (8-inches) in diameter. As a result of the Pipe Explorer™ surveys, much of the piping will be allowed to be left in place. Estimated cost savings are on the order of $1,000,0000.

An example of the data obtained from the GJPO site is shown in Figure 5. A video survey conducted in this same section of pipe showed that each contamination spike corresponded with a location where debris had built up under vertical risers coming from drains in a laboratory.

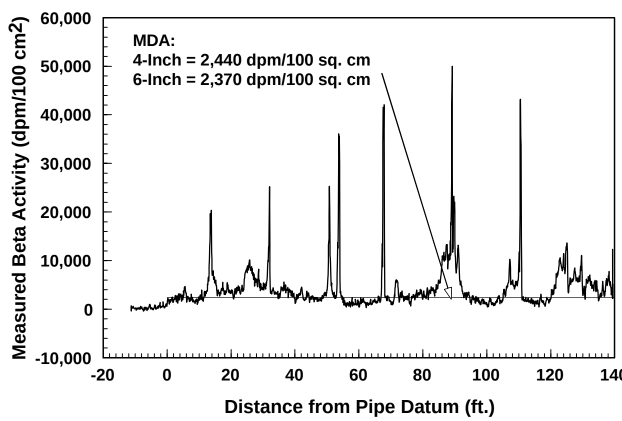

Figure 5. Example data set from surveys conducted at the GJPO site showing localized elevations in surface activity.

E. Argonne National Laboratory, CP-5 Reactor
Illinois – August 1996

This use of the Pipe Explorer™ system was conducted as part of the Argonne National Laboratory - CP-5 Large Scale Demonstration Project. Video and gross gamma surveys were conducted in a 0.1-m (4-inch) diameter exterior drain line. In addition, the Alpha Explorer™ system was used to conduct alpha surveys in concrete embedded fuel rod storage tubes. The performance of the system along with a detailed cost benefit analysis were documented in a DOE Technology Summary Report[3]. The cost benefit analysis compares the Pipe Explorer™ survey costs to the baseline costs of removing and disposing of piping as contaminated waste. The analysis shows that it becomes cost effective to use the Pipe Explorer™ if more than 25-m of piping is involved and the cost savings increase as more piping is included. For instance, if 120 m of piping is surveyed instead of excavated, then the use of the Pipe Explorer™ is a factor of 3 more cost effective than the baseline.

F. DOE Mound Facility
Ohio – November 1996

The Pipe Explorer™ system was used to survey buried radioactive waste drain lines. Gross gamma surveys and periodic spectral measurements were taken to determine the extent of Co-60 contamination in 0.13-m (5-inch) and 0.20-m (8-inch) diameter pipes. In addition, video inspections were conducted. This use of the system represented a case where no cost savings were realized. Contamination above acceptable levels was found and it was determined that the piping could not be cleaned in place. Subsequently, no remediation costs were avoided.

G. Crystal River Nuclear Plant
Florida – October 1997

An inspection of a gate valve in the feed water line of the power plant showed that a hinge pin and a retaining pin had detached from the valve and the parts had been washed downstream in the pipe. Therefore, the Pipe Explorer™ system was used to conduct a video inspection of the 0.46-m (18-inch) diameter pipe to try and locate the objects. A video survey was conducted in the line that included 8 elbows and a 9.4-m vertical rise. The video survey showed that the parts were not located in that portion of the feed water system.

H. Trojan Nuclear Plant
Oregon – November 1997

The Pipe Explorer system was used to conduct gross gamma surveys of 0.10-m (4-inch) diameter drain lines embedded in concrete. The primary contaminant of concern was Co-60. The system was used to measure surface activity both before and after high-pressure water was used to clean the pipes. This project served as a trial run to determine the cleaning and survey methods to use for full-scale remediation of drain lines in the plant.

III. MEASUREMENTS OF SURFACE ACTIVITY

In each of the Pipe Explorer™ radiological surveys discussed previously the response of a beta/gamma, gamma, or alpha detector inside of a pipe was recorded as a function of distance into a pipe. This portion of the paper details how the gross counts recorded from the detectors are translated into a surface activity level. In addition, the method for determining the lower detection limit of the detectors and the speed with which surveys are conducted is presented. Finally, an analysis of the data interpretation methodology is presented.

A. Detector Calibrations

In order to relate the output of Pipe Explorer™ radiation detectors to surface activity, calibrations of the detectors are performed specifically for the expected measurement conditions. The pipe size, pipe material, and isotope of interest are replicated as much as possible. This ensures that attenuation and backscatter effects that will be encountered in an actual measurement situation are mimicked in the calibration process.

The objective of the calibration procedure is to determine an empirical Yield Factor that relates the detector response, in net counts per second (ncps), to a surface activity density in disintegrations per minute per 100 square centimeters (dpm/100 cm^2). This Yield Factor is used to both reduce raw data and to determine the lower detection limit of the measurement conditions. The calibrations are carried out by dividing the interior surface area of a pipe into approximately 2x2 cm grids. A NIST traceable source is moved to each of these grid nodes while the detector response is recorded. An example of a detector response plot resulting from the calibration procedure is shown in Fig. 6.

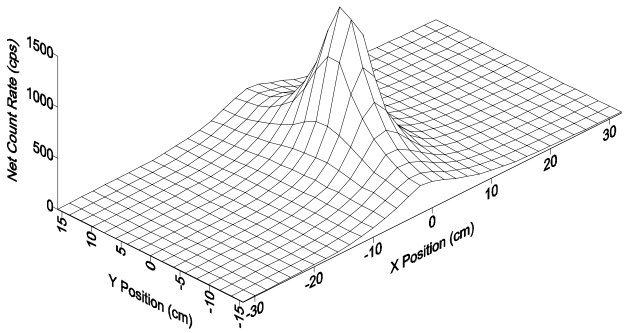

Figure 6. Pipe Explorer™ NaI detector response plot resulting from the calibration procedure. The data was obtained using a NIST traceable Co-60 source in 0.10-m (4-inch) diameter steel pipe.

B. Determination of Lower Detection Limits and Logging Rates

The minimum detectable activity, or MDA, is the minimum activity for a given measurement scenario that can be detected above background with a 95 percent certainty. Specifically, this is a 5 percent chance of concluding that there <u>is</u> activity above the background activity when <u>none</u> is actually present and a 5 percent chance of concluding that there <u>is not</u> activity above the background activity when there actually <u>is</u>. The MDA for measurements is given by the following formula[4]:

$$MDA = \frac{2.71 + 4.65\sqrt{BKR \cdot t}}{Y \cdot t}$$

Where: *MDA* = Minimum Detectable Activity (dpm/100 cm^2)
BKR = Background Count Rate (cps)
Y = Yield Factor [net cps/(dpm/ 100 cm^2)]
t = The count time (s)

To determine the logging rate of a Pipe Explorer™ survey, a sample time is chosen such that the MDA is well below a pre-selected criteria level. For example, the threshold value limit for U-238 is 5,000 dpm/100 cm^2. The Yield Factor of a Pipe Explorer™ detector in 4-inch pipe is 1.85E^{-3} cps/(dpm/100 cm^2). A sample time of 3 s would be selected for this measurement, as it gives an MDA of 3,000 dpm/100 cm^2 (assuming 3 cps background). This MDA is well below the criteria level of 5,000 dpm/100 cm^2. The Pipe Explorer™ logging rate is then set by the condition that the detector travels a distance no more than the length of the detector window during one sample interval. The detector in this example has a window length of 0.047 m. Therefore, the logging rate would be 0.047 m/3 s or 3.1 ft/min.

To illustrate the meaning of the MDA and how it relates to logging rates, a Pipe Explorer™ detector was used to survey a short section of pipe that had a large area Co-60 source placed inside of it. The source has a surface area of 150 cm^2 with a NIST traceable surface activity of 659 dpm/100 cm^2. A NaI Pipe Explorer™ detector was transported through the pipe section. Data was taken over a 270 s period while the detector was moved 5.1-cm at a time (the length of the detector window). The Yield Factor determined for the detector was 1.57E^{-3} cps/(dpm/100 cm^2). Thus, the calculated MDA for the measurement is 654 dpm/100 cm^2 (12.9 cps background). The data obtained is plotted in Figure 7. The data clearly shows an elevation in surface activity well above the variation in background.

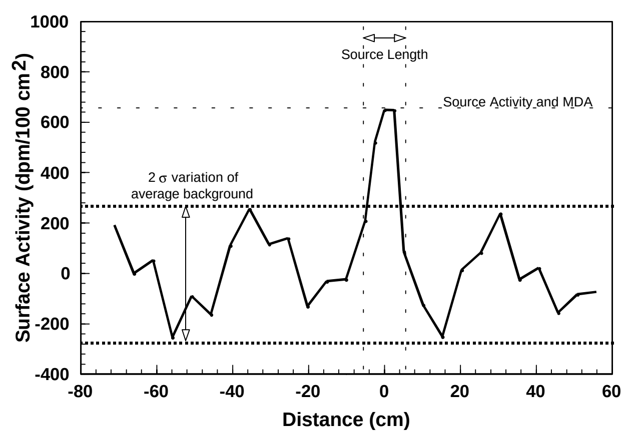

Figure 7. Laboratory data obtained with a NaI detector transported through a 0.10-m diameter pipe with a 659 dpm/100 cm^2 Co-60 source placed inside of it.

C. Detector Measurement Geometry

The uses of the Pipe Explorer™ system have predominately taken place in small diameter piping systems (ID <0.15 m). With the limited space inside small diameter pipes the ability to center a detector is restricted by the necessity to retain the ability to negotiate multiple elbows. Centering hardware adds significantly to the size and weight of a detector housing, which limits maneuverability around elbows and over obstructions. For instance with centering hardware on robotic crawlers or detectors directly inserted in pipes, deployments are typically limited to two or less elbows. Most in-situ pipe surveys require that the detector travel around three or more elbows. Furthermore, the detector necessarily must be smaller to accommodate centering hardware, which sacrifices measurement sensitivity. With this in mind, the Pipe Explorer™ suite of detectors were designed to have maximum sensitivity, while being able to negotiate as many as 8 elbows. This results in a measurement geometry consisting of a detector with a 360-degree field of view that travels along the gravitational bottom of the pipe.

While this optimizes the sensitivity and deployment capabilities of the detector, it also requires that some assumption be made as to the distribution of contamination in the pipe. Historically the procedure employed has been to assume a conservative contamination geometry, such that reported surface activities would never be understated. A less conservative approach is to make a reasonable assessment of the contamination distribution and then analyze the error in reported surface activities levels if the contamination geometry is different from the assumed distribution. Most of the pipes that have been surveyed with the Pipe Explorer™ have been drain line systems where liquid flow is sporadic and rarely fills the pipe. In such situations it is reasonable to assume that contamination is predominately located in the bottom half of the pipe.

As an example of how these contamination distribution assumptions affect the interpretation of data gathered from Pipe Explorer™ detectors, two cases are analyzed using calibration data from 0.10-m (4-inch) and 0.15-m (6-inch) diameter pipes. The calibration data consists of the response of a β/γ detector to a Sr/Y-90 source in both pipe geometries. The data was obtained in each pipe by moving the source relative to the detector in 2-cm increments both along the axis of the pipe and around the circumference. The resulting matrix of data points is used in this analysis to determine the effective response of the detector to various contamination distribution scenarios.

The baseline configuration in the analysis is that Sr/Y-90 contamination is evenly distributed along the length of a pipe, but restricted to the lower half. A Yield Factor for this geometry is derived that is used to translate gross counts recorded from the detector to an average surface activity over the pipe interior. The calibration data is then used to determine the extent to which the surface activity would be over or under reported if the contamination distribution scenario varies from the baseline condition. The ratio of actual surface activity to surface activity that would be reported as a function of the portion of the circumference covered with contamination is shown in Figure 8.

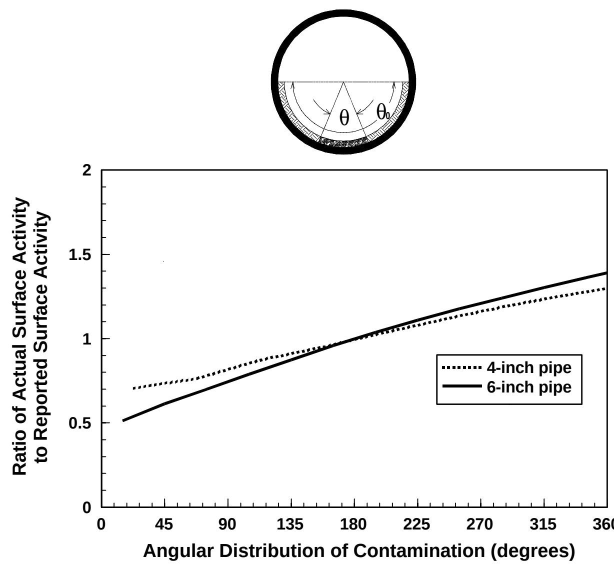

Figure 8. Analysis of the error introduced if contaminant distribution varies from assumed conditions. The assumed distribution is a 0.54-m long section of contamination distributed evenly over the lower half of the pipe. θ_0 is the assumed angular distribution of contamination (180 degrees). θ is the actual contamination distribution.

The data of Fig. 8 shows that if the contamination in a pipe is evenly distributed around the circumference (θ=360 degrees) instead of just the lower half of the pipe (θ_0=180 degrees), then the contamination would be understated by 30 percent and 40 percent for 0.10 m (4-inch) and 0.15 m (6-inch) pipe respectively. Conversely, if the contamination is actually localized to the very bottom of the pipe then the contamination would be overstated by roughly 30 percent and 50 percent for 0.10-m and 0.15-m diameter pipe respectively. As expected, the error increases with increasing pipe diameter since the ratio of detector diameter to pipe diameter decreases.

The case of the 0.15-m diameter pipe represents a worst case scenario since the data was obtained with a detector designed to fit inside of 0.05-m diameter piping. In reality larger area detectors are used in larger diameter pipes, which counteracts this uncertainty. Furthermore in pipes with diameter greater than 0.20-m, detector centering hardware can be used.

III. SUMMARY

The Pipe Explorer™ system has proven to be a valuable tool in effecting the efficient decontamination and decommissioning of various DOE and commercial sites. The Pipe Explorer™ offers the D&D project manager a cost-effective means of characterizing the levels of residual radioactive contamination inside of pipes and duct work. With the Pipe Explorer™, these piping or duct systems may be adequately characterized for radiological contamination. If contamination is found, various decontamination methodologies can be employed, and their success verified with Pipe Explorer™, resulting in a high level of confidence that the site will be appropriately remediated at the lowest possible cost.

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